# HELICITY FLIP IN DIFFRACTIVE DIS

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I review new results on $s$-channel helicity nonconservation (SCHNC) in diffractive DIS. I discuss how by virtue of unitarity diffractive DIS gives rise to spin structure functions which were believed to vanish at $x \ll 1$. These include tensor polarization of sea quarks in the deuteron, strong breaking of the Wandzura-Wilczek relation and demise of the Burkhardt-Cottingham sum rule.
The invited talk at QCD & Multiparticle Production, XXIX International Symposium on Multiparticle Dynamics (ISMD99), August 9-13, 1999. Brown University, Providence, RI 02912, USA

## 1 Introduction

The often repeated argument is that diffractive scattering is driven via unitarity by absorption due to multiparticle production. The common wisdom is that this entails vanishing spin-dependence of diffractive scattering. The related QCD argument has been that quark helicity conservation entail the $s$-channel helicity conservation (SCHC) at small $x$, i.e., decoupling of QCD pomeron from helicity flip. Here I review the recent discovery [1,2,3,4,5,6] of substantial SCHNC in diffractive DIS into the both continuum and vector mesons. Furthermore, SCHNC diffractive DIS in conjunction with unitarity changes dramatically the small-$x$ behaviour of spin structure function $g_2$ and leads to the demise of the Burkhardt-Cottingham sum rule and the departure from the Wandzura-Wilczek relation. Still another diffraction driven spin effect is the tensor polarization of sea quarks in the deuteron.

## 2 Is SCHNC compatible with quark helicity conservation?

The backbone of DIS is the Compton scattering (CS) $\gamma^*_\mu p \to \gamma^{*'}_\nu p'$. The CS amplitude $A_{\nu\mu}$ can be written as $A_{\nu\mu} = \Psi^*_{\nu,\lambda\bar{\lambda}} \otimes A_{q\bar{q}} \otimes \Psi_{\mu,\lambda\bar{\lambda}}$ where $\lambda, \bar{\lambda}$ stands for $q, \bar{q}$ helicities, $\Psi_{\mu,\lambda\bar{\lambda}}$ is the wave function of the $q\bar{q}$ Fock state of the photon. The QCD pomeron exchange $q\bar{q}$-proton scattering kernel $A_{q\bar{q}}$ does not depend on, and conserves exactly, the $q, \bar{q}$ helicities. For nonrelativistic massive quarks, $m_f^2 \gg Q^2$, one only has transitions $\gamma^*_\mu \to q_\lambda + \bar{q}_{\bar{\lambda}}$ with $\lambda + \bar{\lambda} = \mu$. However,

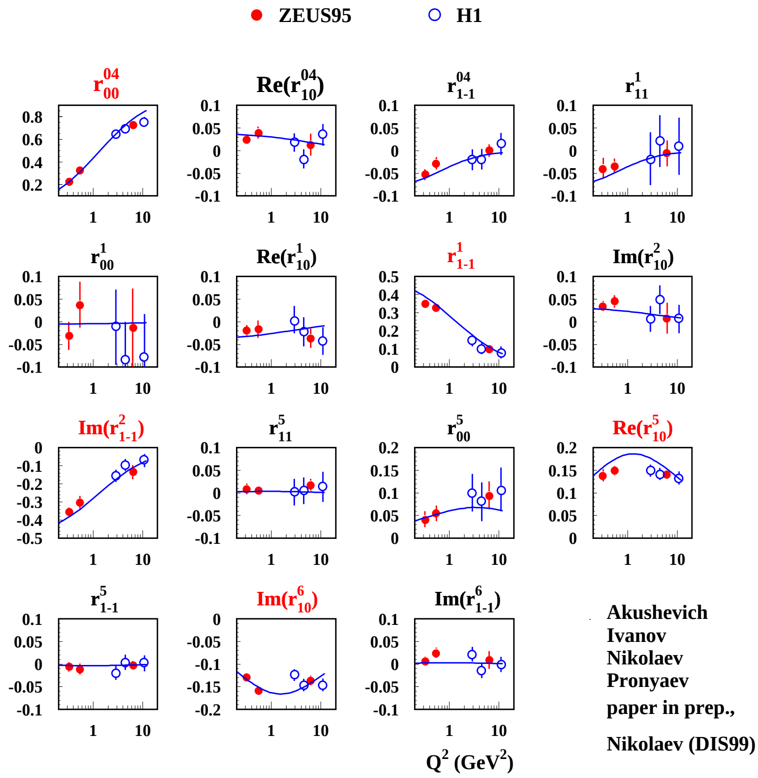


Figure 1: Our prediction [5] for the spin density matrix $r^n_{ik}$ of diffractive $\rho^0$-meson vs. the experimental data from ZEUS [8] and H1 [9].

the relativistic P-waves give rise to transitions of transverse photons $\gamma^*_\pm$ into the $q\bar{q}$ state with $\lambda+\bar{\lambda}=0$ in which the helicity of the photon is transferred to the $q\bar{q}$ orbital momentum. Consequently, the QCD pomeron exchange SCHNC transitions $\gamma^*_\pm \to (q\bar{q})_{\lambda+\bar{\lambda}=0} \to \gamma^*_L$ and $\gamma^*_\pm \to (q\bar{q})_{\lambda+\bar{\lambda}=0} \to \gamma^*_\mp$ are allowed [1,2] and SCHNC persists at small $x$. We emphasize that the above argument for SCHNC does not require applicability of pQCD.

## 3 LT interference and SCHNC in diffractive DIS

The first ever direct evaluation [1] of SCHNC effect in QCD - the LT-interference of transitions $\gamma^*_L p \to p'X$ and $\gamma^*_\pm p \to p'X$ into the same continuum diffractive states $X$ - has been reported in 1997. Experimentally, it can be measured at

HERA by both H1 and ZEUS via azimuthal correlation between the $(e, e')$ and $(p, p')$ scattering planes and can be used the determination of the otherwise elusive $R = \sigma_L/\sigma_T$ for diffractive DIS is found in [2]. The principal issue is that this asymmetry persists, and even rises slowly, at small $x_{\mathbf{IP}}$.

The azimuthal correlation of the $(e, e')$ and $(p, V)$ planes with the vector meson decay plane, and the in-decay-plane angular distributions of decay products, allow the experimental determination of all helicity amplitudes $A_{\mu\nu}$ for diffractive $\gamma^* p \to V p'$. One finds that helicity flip only is possible due to the transverse and/or longitudinal Fermi motion of quarks and is extremely sensitive to spin-orbit coupling in the vector meson, I refer for details to [3,4]. The consistent analysis of production of the $S$-wave and $D$-wave vector mesons is presented only in [4]. One would readily argue that by exclusive-inclusive duality [7] between diffractive DIS into continuum and vector mesons [1,2] the dominant SCHNC effect in vector meson production is the interference of SCHC $\gamma^*_L \to V_L$ and SCHNC $\gamma^*_T \to V_L$ production, i.e., the element $r^5_{00}$ of the vector meson spin density matrix. The overall agreement between our theoretical estimates [5] of the spin density matrix $r^n_{ik}$ for diffractive $\rho^0$ and the ZEUS [8] and H1 [9] experimental data is very good. There is a clear evidence for $r^5_{00} \neq 0$.

In the $D$-wave state the total spin of $q\bar{q}$ pair is predominantly opposite to the spin of the $D$-wave vector meson. As a results, SCHNC in production of $D$-wave vector mesons is much stronger [4] than for the ground state S-wave mesons, which may facilitate the disputed $D$-wave vs. $2S$-wave assignment of the $\rho'(1480)$ and $\rho'(1700)$ and of the $\omega'(1420)$ and $\omega'(1600)$. Striking predictions for D-wave meson production include abnormally large higher twist corrections [4] and non-monotonous $Q^2$ dependence of $R^D = \sigma_L/\sigma_T$.

## 4 Impact of diffraction upon $g_2$: breaking of the Wandzura-Wilczek relation and demise of the Burkhardt-Cottingham sum rule

The transverse spin asymmetry $A_2$ in polarized DIS is proportional to the amplitude of forward CS $\gamma^*_L p\!\uparrow \to \gamma^*_T p\!\downarrow$ which is proportional to $g_{LT} = g_1 + g_2$. In the standard two-gluon $t$-channel tower approximation the cross-talk of the target and beam helicity flip only is possible at the expense of suppression of the small-$x$ behaviour of $x^2 g_{LT}$ by the extra factor $\sim x$ compared to $F_1$, because not both gluons in the pomeron can have the nonsense polarization simultaneously.

The more familiar argument for the vanishing $A_2$ has been the parton model Wandzura-Wilczek relation between $g_{LT}$ and $g_1$ [11]:

$$g_{LT}(x, Q^2) = \int_x^1 \frac{dy}{y} g_1(x, Q^2)\,,$$

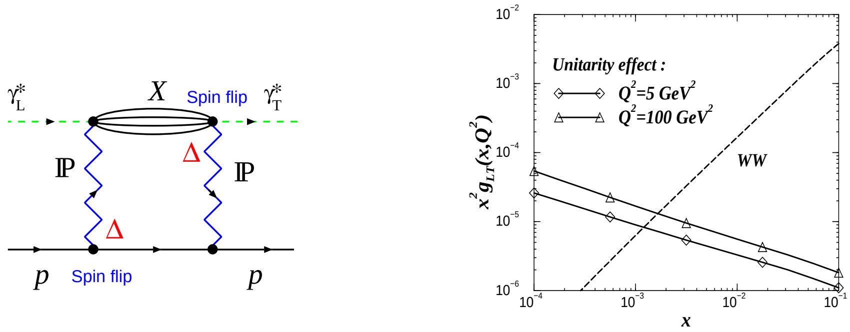


Figure 2: The LHS: The unitarity diagram for diffractive contribution to $g_{LT}$. The RHS: The unitarity correction to, and WW relation based evaluation of, $g_{LT}$.

which entails $g_{LT} \sim g_1$. Because the diffractive pomeron exchange does not contribute to $g_1$, the WW relation can be reinterpreted as a vanishing pomeron exchange contribution to $g_{LT}$. This vanishing of the pomeron contribution has been the principal motivation behind the much discussed Burkhardt-Cottingham [12] (BC) sum rule $\int_0^1 dx g_2(x,Q^2) = 0$.

Our recent discovery is that diffractive SCHNC destroys via unitarity the both WW relation and BC sum rule [6]. The unitarity diffractive contribution (fig. 2) to CS has as building blocks diffractive amplitudes $\gamma^* p \to p' X$ in which there is a helicity flip sequence, $\gamma^*_L \to X_L \to \gamma^*_T$ in the top blob and helicity flip sequences either $p\!\uparrow\to p'\!\uparrow\to p\!\downarrow$ or $p\!\uparrow\to p'\!\downarrow\to p\!\downarrow$ in the bottom blob. The both blobes are proportional to $\mathbf{\Delta}$ and vanish for forward produced $X$, but upon the integration over the phase space of $p'X$ one finds the nonvanishing $\int d^2\mathbf{\Delta}\Delta_i\Delta_k$ and unitarity driven transition $\gamma^*_L p\!\uparrow\to \gamma^*_T p\!\downarrow$ which does not vanish in the forward direction. The principal point is that the unitarity diagram furnishes the cross-talk of the beam and target helicity flip with pure nonsense polarizations of all the four exchanged gluons in the two pomerons.

Our result [6] for the diffraction-driven $g_{LT}$ reads

$$g_{LT}(x,Q^2) \propto \frac{1}{x^2} r_5 \int_x^1 \frac{d\beta}{\beta} g^D_{LT}(x_{\mathbf{I\!P}} = \frac{x}{\beta}, Q^2)\,. \qquad (1)$$

It rises steeply at small $x$. It is the scaling function of $Q^2$ because the diffractive LT structure function $g^D_{LT}(x_{\mathbf{I\!P}}, Q^2)$ is the scaling one. The resulting asymmetry $A_2 \propto x g_{LT}/F_1$ does not vanish at small $x$, furthermore, at a moderately small $x$ it even rises because $g^D_{LT}(x_{\mathbf{I\!P}}, Q^2) \propto G^2(x_{\mathbf{I\!P}}, \overline{Q}^2)$ where $G(x_{\mathbf{I\!P}}, \overline{Q}^2)$ is the gluon SF of the proton and $\overline{Q}^2 \sim 0.5$-$1$ GeV$^2$.

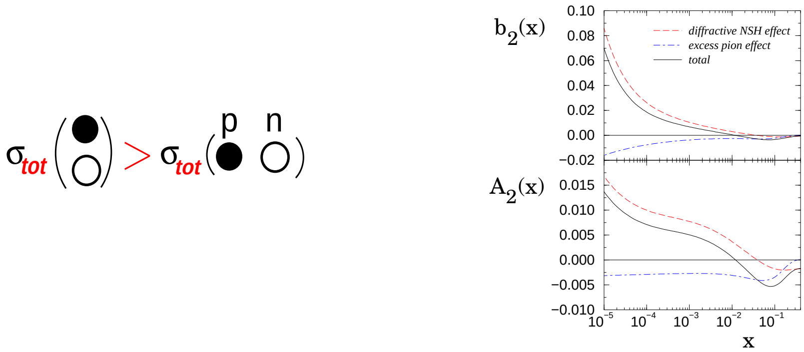


Figure 3: The LHS: The unitarity diagram for diffractive contribution to $g_{LT}$. The RHS: The unitarity correction to, and WW relation based evaluation of, $g_{LT}$.

In fig. 3 we show how the steeply rising unitarity correction overtakes at small $x$ the standard $g_{LT}$ evaluated from the Wandzura-Wilczek (WW) relation starting with fits to the world data on $g_1$. As such our unitarity effect is the first nontrivial scaling departure from the WW relation

Finally, the above breaking of the WW relation implies $g_{LT} \gg g_1$ and $g_2 = g_{LT}$ at very small $x$. Consequently, the unitarity-driven rise of $g_2$ destroys the BC sum rule because the BC integral would diverge severely. Incidentally, the BC sum rule has always been suspect.

## 5 Diffraction, unitarity and tensor structure function of the deuteron

The deuteron is an unique spin-1 target. Because of the S-D wave interference it is a dumbbell and spatial orientation of nucleons and their Fermi motion in the deuteron depend on its polarization which may give rise to the dependence of parton densities on the tensor polarization of the deuteron. In the impulse approximation the tensor structure function $b_2(x)$ is found to be negligible, per mill, effect [14] and satisfies the Close-Kumano sum rule [15] $\int_0^1 \frac{dx}{x} b_2(x) = 0$. Close and Kumano conjectured this is a generic QCD sum rule.

Fig. 3 makes it obvious that diffractive eclipse effect in the deuteron depends on its orientation which is controlled by tensor polarization. The results of the calculation [13] of the eclipse effect are shown in fig. 3. The tensor polarization of the sea measured by tensor asymmetry $A_2$ is quite substantial and persists at small $x$. Apart from diffractive eclipse effect, it receives a small contribution also from the pion exchange [13].

**Conclusions**

Drastic revision of our prejudice on spin-independence of diffraction is called upon. The recent fundamental finding is that QCD pomeron exchange does not conserve the $s$-channel helicity. The mechanism of SCHNC is well understood. SCHNC offers an unique window at the spin-orbit coupling in vector mesons. SCHNC in diffractive DIS drives, via unitarity relation, a dramatic small-$x$ rise of the transverse spin structure function $g_2$ which breaks the Wandzura-Wilczek relation and invalidates the Burkhardt-Cottingam sum rule. The related unitarity effect is the tensor polarization of sea quarks in the deuteron which persists at small $x$.

**Acknowledgments.** I'm indebted to C.-I.Tan for the invitation to ISMD-99.

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